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Non-Linear Mapping for Improvement of Display Comprehension of Low Resolution Images

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ABSTRACT

This paper describes the development and testing of Nonlinear Display Mapping (NDM), which is high-speed digital signal processing to quickly manipulate displayed images. The identification performance of observers using an automated algorithm and observers using NDM are compared. The observer utilizes NDM to improve image understanding. No algorithm or automatic method can optimize thermal displays for every environment, condition and target. Often, the manual controls are used when "auto mode" does not work well. The commonly available manual brightness and contrast controls are difficult to use and do not fully realize the potential of digital systems. Also, recent experiments showed that the auto mode might combine contrast shades such that targets or target features are hidden from the observer. Current display algorithms employ a wide variety of methods, including histogram equalization, local area processing, and region of interest processing. Non-linear Display Mapping (NDM) differs from these because it allows the user to manipulate the displayed intensity of different regions of the sensor output by real-time non-linear mapping to pixel values. The user can thus allocate or "tune" pixel intensities (gray shades) to output regions expected to contain targets. This avoids squandering the system's limited dynamic range on image features such as cold sky, clouds, trees or water. In other words, NDM enables the user to tune the sensor to the scene.

1. INTRODUCTION

The Night Vision Electronic Sensing Directorate Modeling Branch studied various sensor effects in the late 1990's through still-image degradation experiments. The effects of blur, sampling noise, spurious response and other variables on target identification were studied in experiments that used a standard set of 12-target 12-aspect high-resolution 12-bit thermal images as a baseline[1]. Once degraded, these images had to be optimized for 8-bit displays and it was found that no single technique could consistently deliver good contrast across the entire set of images while retaining critical target information. A novel method of non-linear mapping was devised that allowed the image processor to view the image histogram and determine non-linear bit allocations for display based on observable target features. Any target image could be quickly processed to achieve 50% contrast through this method.

Thermal sight users would benefit from such target contrast improvements if they could be achieved at a reasonable cost. Software was developed to simulate a simple non-linear sensor control. Over 900 high-, medium- and low-resolution thermal images with over 50 targets and 6 different backgrounds were processed for expert analysis. That analysis suggested that while non-linear mapping could improve target contrast for almost all studied conditions and targets, it would be most beneficial under conditions of moderate to high blur and moderate to low target resolvability. When blur is low and resolution

high, little improvement is possible because the observer has adequate target information to ID, regardless of target contrast. In conditions of very high blur and very low resolution, the target becomes an amorphous blob, and it is not possible to distinguish target features under any circumstances. Non-linear contrast enhancements are thus most beneficial between those extremes.

A low-resolution highly blurred target set with a predicted probability of ID under 30% tests the extreme limit of non-linear mapping's potential to improve image comprehension. The B-kit automatic algorithm emulator was chosen for comparison because it is scene based, known to produce relatively good target contrast under most conditions, and similar algorithms are incorporated into 2nd generation FLIR systems.

Night Vision Electronic Sensors Directorate researchers conducted a forced-choice vehicle ID experiment in which 20 trained subjects were shown low resolution images processed with a B-kit automatic algorithm emulator and with Non-linear Display Mapping (NDM) techniques. Subjects viewed 50 images processed with each method presented in a randomized order. The mean probabilities of identification for B-kit automatic and NDM were 25% and 32% respectively. Nineteen of 20 observers had higher scores with NDM, and the improvement range was 12% to 100%. The average improvement was 28%.

2. BACKGROUND AND PURPOSE

The 2nd generation Forward Looking Infrared (FLIR) imaging systems currently being developed and fielded have digital data output, whereas 1st generation FLIR's have analog output. Analog display controls generally allow the user to manipulate the brightness and contrast of the image, but such controls affect the entire data output signal, (generally 8 bit), and can introduce additional noise that obscures comprehension. While displays are often still limited to 8 bits, the output signal of the 2nd generation FLIR is twelve bits or more and, because it is digital, can be mapped to the display in numerous ways. Thus, regions of the 12-bit output signal are accentuated, or de-emphasized or eliminated when mapped to the 8-bit display.

Automatic algorithms and methods, such as region of interest and local area processing are useful image comprehension aids in some conditions, but the dynamic variability of thermal scenes and targets ultimately confounds these methods. The automatic method is not capable of prioritizing displayed gray shades based on subjective, situational or qualitative scene information. For example, significant gray shades may be allocated to a temperature gradient across the sky. When this occurs, image comprehension is lowered because gray shades that could have increased target internal contrast or other relevant information are allocated to the irrelevant sky temperature gradient.

The purpose of this Non-linear Display Mapping (NDM) research is to determine the level of image comprehension improvement gained by allowing the user to tune the sensor display to the scene. This is achieved by the user's active control of gray shade mapping to meet his comprehension or target acquisition needs. Figure 1 depicts

allocation of gray shades to expected target signal region. The user can thus employ subjective, situational and qualitative scene information to improve the displayed image. NDM does not increase perceived noise to achieve contrast improvement, as would be expected with analog gain and level controls. Thus, if sky temperature gradients, bodies of water, fires or hot pavement are interfering with scene comprehension, the user may "tune them out" by allocating a small or even single gray shade to those scene features. As the scene or task changes, the user can adapt the display to meet the current need. The user can also increase the gray shades allocated to objects of interest within the scene.

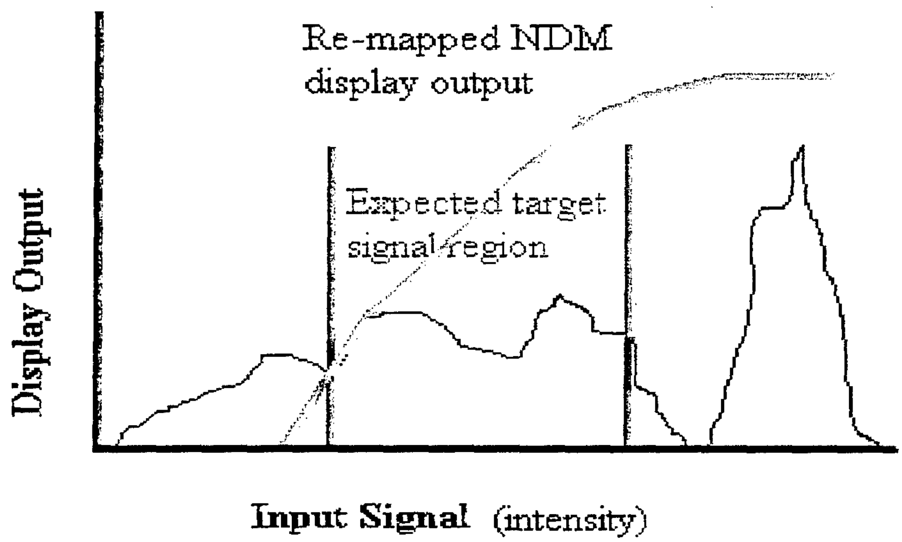


Figure 1. The NDM Concept

4. IMAGE SELECTION AND PROCESSING

Fifty frame-averaged 12-bit thermal images from an Agema 1000 longwave imager were selected for an ID experiment. Each image included one of nine tracked vehicle targets in the foreground, and mid-latitude dense forest in the background. The vehicles were: 2S3, BMP-1, M109A5, M113A2, M1IP, M2A2, T-62, T-72, and ZSU-23/4 (see Figure 2). Five to 7 of 8 different aspect orientations were selected for each vehicle (see Figure 3). This group of vehicle images represents a broad range of discrimination difficulty within the category of tracked vehicles for the identification task. This vehicle set also represents a good sample of the types of foreign and US tracked vehicles in current use. The images were collected at a range of 400m with a 20 x 13 degree field of view (FOV) and resolution of 590 x 401 pixels. The target in each image was centered, obviating the need for any search by the observer. The number of pixels on target was small, (from 160 to 400 pixels), occupying less than .2% of the total image area. It is important to note that the range and FOV selected represent a discrimination significantly beyond the expected 50% probability of ID (P(id)), where image information is highly constrained by blur (and thus lower target internal contrast) and resolution (pixels on target).

The 50 selected images were processed using a B-kit automatic algorithm emulator, developed by E-OIR measurements for the Night Vision Electronic Sensors Directorate (NVESD). The automatic algorithm emulator required no user input, and the display parameters were determined by the overall scene characteristics. Concurrently, the same 50 images were processed with NDM software developed by NVESD. The NDM software user viewed representative images and their histograms for each of the five collection environments from which images were drawn. The user then determined regions to be compressed or enhanced. Scene characteristics such as cold sky and hot ground were suppressed for the NDM processed images. Images from the same location and collection date were processed using the same NDM suppression and enhancement parameters to represent sensor output optimized for the scene, rather than for the target. This eliminated any bias based on user knowledge of the specific target in each image and its critical features or characteristics. The result of the two processing paths above yielded a total of 100 images (50 B-kit automatic and 50 NDM) that were presented to the subjects in a forced-choice vehicle ID computer perception test. This test software was initially developed by NVESD and has been used with a multitude of image sets to conduct over 20 different experiments over the last four years.

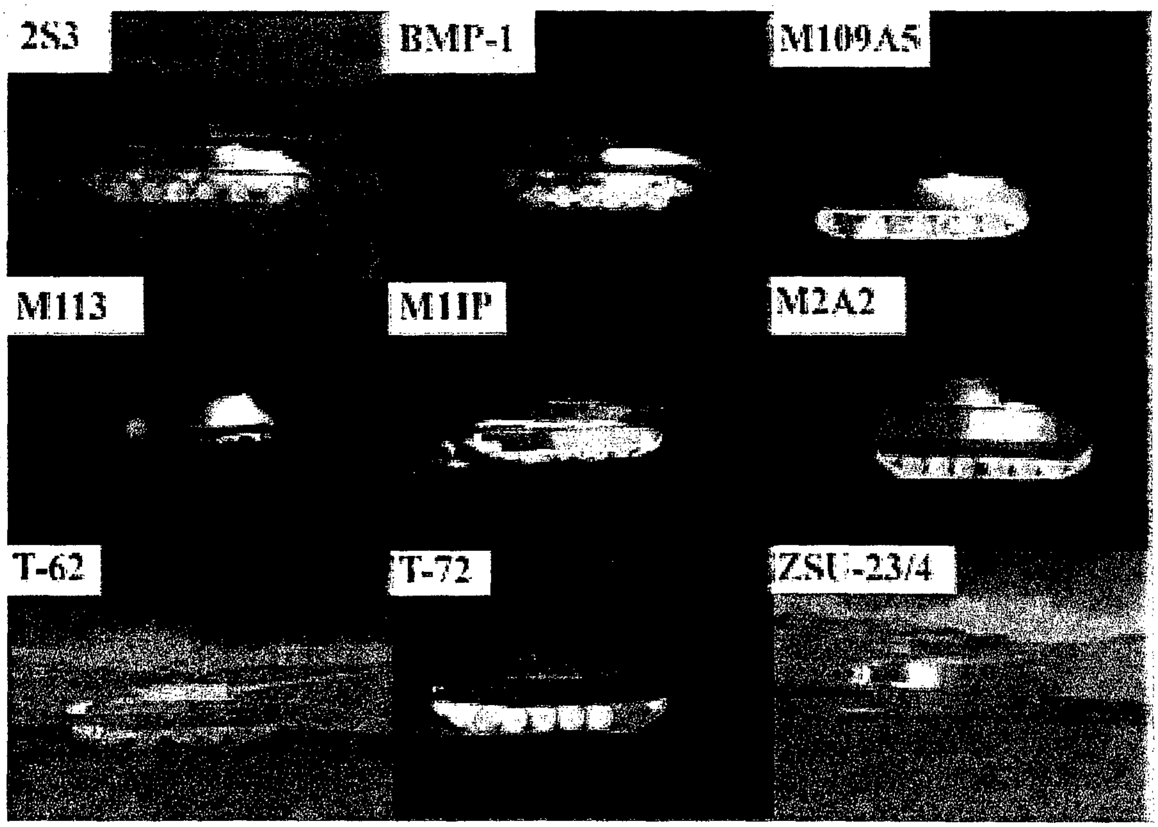


Figure 2. Vehicle targets types

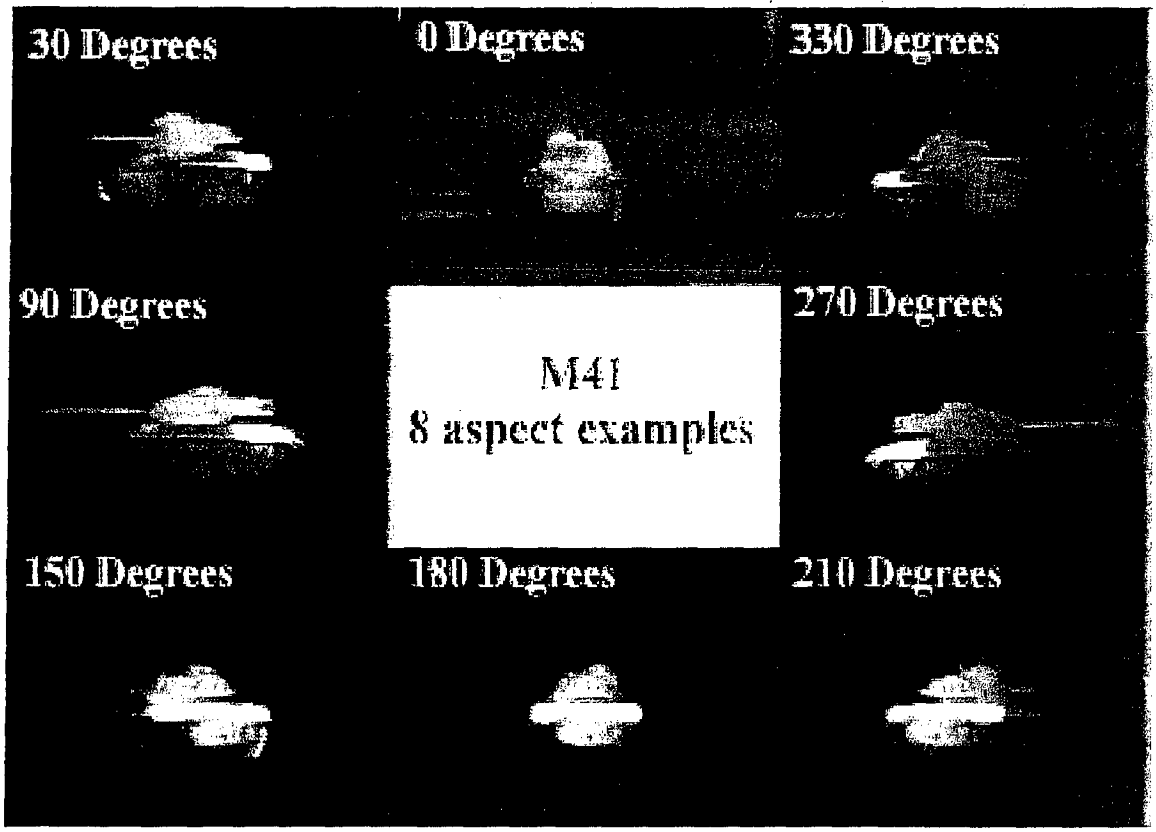
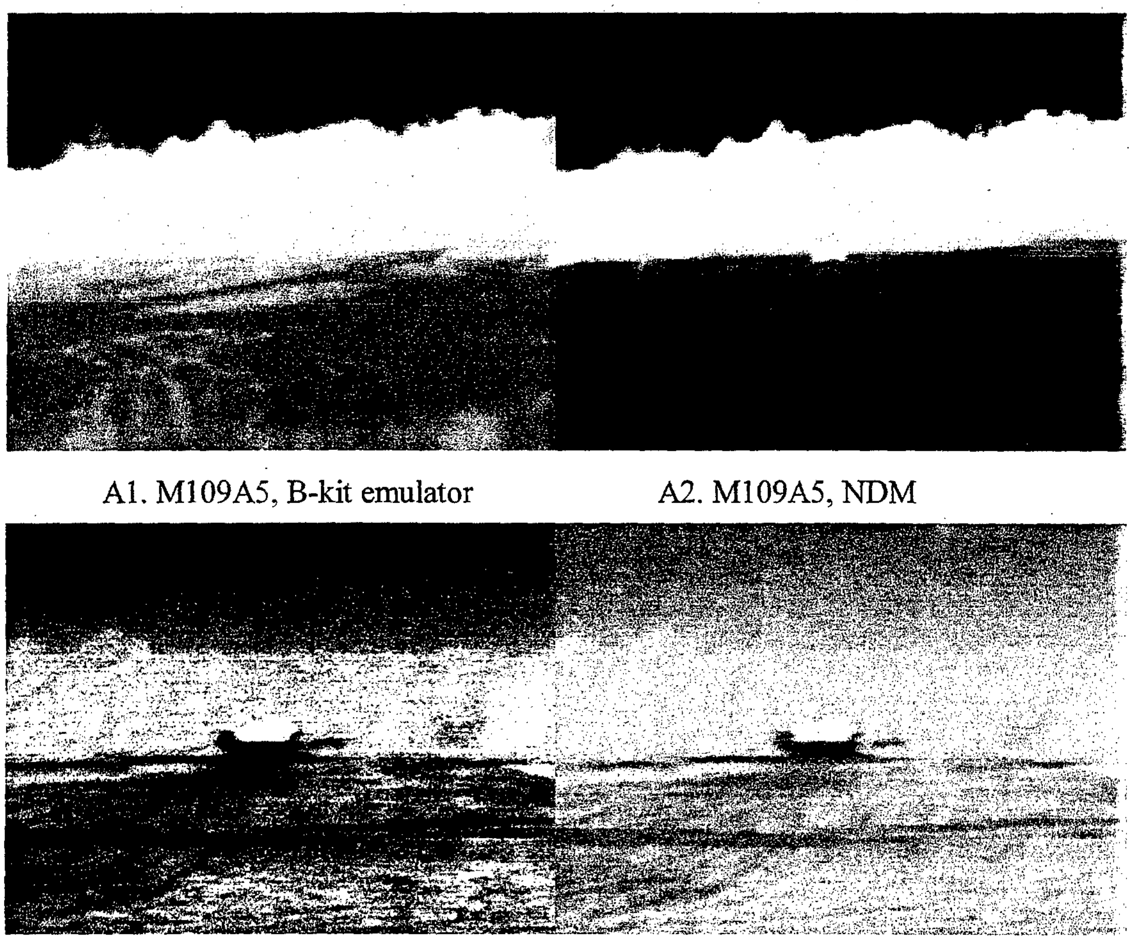


Figure 3. Vehicle image aspects

Figure 4 is a sample of the experimental imagery for each treatment, and A1 and A2 were generated from the same base image. It is easy to notice the relatively large number of gray shades allocated to the sky in A1, whereas in A2 the sky is reduced to a single gray shade. Note the greater internal target contrast of A2, and the separation of the target silhouette from the tree line. The greater target to background contrast and internal target contrast of A2 is made possible by the re-allocation of gray shades from cold sky temperatures, where there is little meaningful information, to expected target temperatures.

Images B1 and B2 in Figure 4 were generated from a base image different in location and environmental conditions from A1 and A2. The overcast sky in B1 and B2 is much closer to ambient temperature than in A1 and A2, where no clouds are evident. Note that the automatic algorithm emulator in B1 allocates many gray shades to the tree line but saturates the target, revealing little internal target detail. While the overall scene in B2 is lower contrast than B1, the target has good internal contrast, revealing the unsupported tracks, the location of the engine and exhaust, the turret crease, the folded radar dish, and other cues that distinguish this vehicle as a ZSU-23/4.



A1. M109A5, B-kit emulator A2. M109A5, NDM

B1. ZSU-23/4, B-kit emulator B2. ZSU-23/4, NDM

Figure 4. Low-resolution experimental image examples

5. EXPERIMENTAL METHOD

All test subjects were required to train to a 96% medium range P(id) standard (less than 1500 pixels on target) for the experimental set of nine vehicles before participating in this experiment. The US Army's *Recognition of Combat Vehicles*[2] (ROC-V) thermal signature training software was used to achieve this level of proficiency. Training thermal signatures is necessary for thermal ID experiments to reduce error introduced by guessing. For example, if a test subject is only 30% proficient in a set of 10 vehicles at close range (he can only positively ID 3 of 10), 70% or more of his ID calls for that set may be guesses. This introduces random error into the experimental data and reduces the reliability of results. Further, well-trained subjects can extract or deduce information from an image that less well-trained subjects cannot.

Subjects were individually administered the 100-image computer perception test discussed above upon completion of the required ROC-V training. Subjects were sequentially shown the images in randomized order and required to select the most likely vehicle identity based on what they could discern from the image. Images could not be

skipped or revisited. No time limit, per image or for the test overall, was imposed. Users received no feedback until the test's completion, and scores or any other aspects of the test were not discussed until all subjects had completed their tests. Subject test results were recorded as individual files for each individual. These files included subject identifiers, the image presentation order, and the scores, target calls and time between target calls for each image. It is important to note that the test imagery was collected separately from the ROC-V training imagery to avoid artifactual image identification, rather than the desired vehicle identification.

6. RESULTS

Twenty well-trained thermal sight users completed NVESD perception test. The mean scores for B-kit automatic and NDM images were 25.0 % (14% above chance) and 32.0% (21% above chance) respectively. Respective standard deviations were .78 and .74 (1.6% and 1.5%). The high and low scores for the B-kit treatment were 52% and 16%, with 70% of subjects scoring between 16% and 30%. The highest and lowest NDM treatment scores were 64% and 20%, with 70% of subjects scoring between 24% and 40%. Figure 5 illustrates each individual's ID performance with each treatment; with subjects ordered by B-kit treatment score. The error bars indicate that 19 of 20 subjects had significantly higher scores for the NDM treatment. NDM scores for those who improved were from 12% to 100% higher.

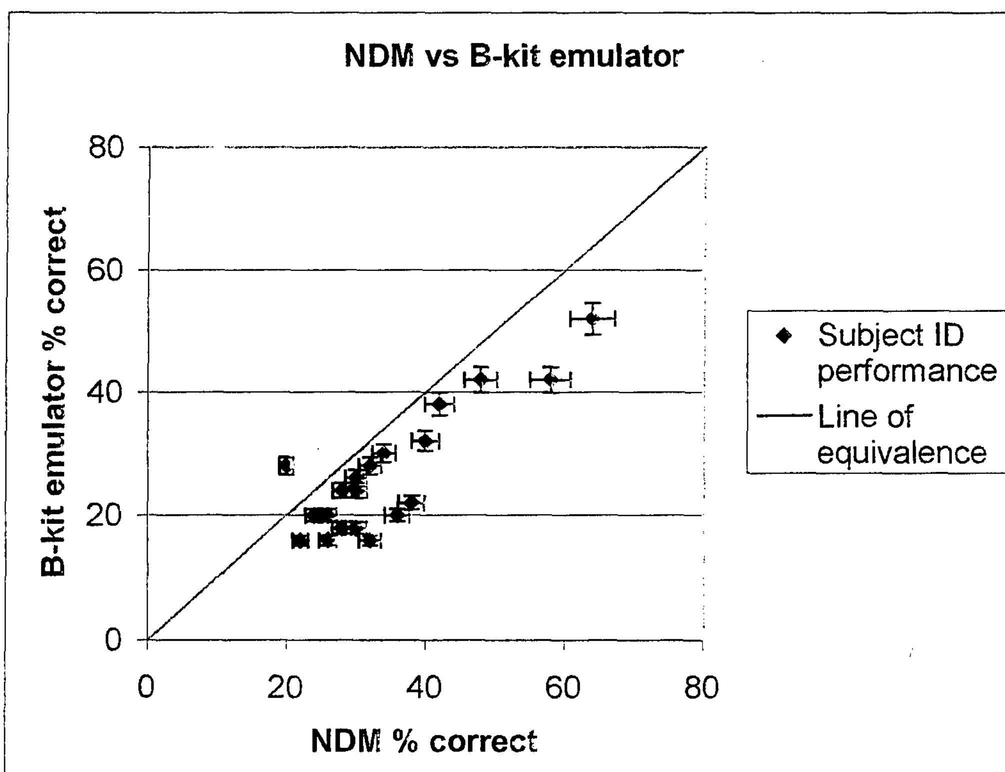


Figure 5. Low-resolution ID performance, NDM versus B-kit emulator

7. CONCLUSION

If the treatments were theoretically equal, the probability of 19 of 20 observers scoring higher with NDM would be 21 in 1,048,576. There is thus a better than 99.9% probability that NDM does improve comprehension with images having low resolution on target. Further experiments will measure the degree to which NDM can be expected to improve identification probabilities and reduce cycle criteria for N_{50}.[3]

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3. John Johnson, "Analysis of Image Forming Systems", Proc. of Image Intensifier Symposium, 1958, pp. 249-273.